aim of the Department is to obtain a depth of 30 feet at low water, and with this in view it is anticipated that, the sand-movement question having been dealt with satisfactorily by the proposed breakwater-extension and the assistance of the dredger "Jupiter," the work of removing the rock from 23 feet down to 30 feet will be lightened appreciably.

In conclusion, the Author desires to thank Mr. E. M. de Burgh, M. Inst. C.E., Chief Engineer for Harbours and Water-Supply, for his permission to submit this Paper, and also for his kindly criticism and assistance during its preparation.

The Paper is accompanied by one tracing and a print, from which Plate 6 has been prepared; there are also two photographs.

(*Paper No. 3897.*)

"Fremantle Harbour-Works, Western Australia."

By Charles Stuart Russell Palmer, M. Inst. C.E.

Western Australia covers about one-third of the island continent, being demarcated politically from the rest of Australia by the 129th meridian of east longitude. On the other three sides it is bounded by the Indian and Southern Oceans. In comparison with the large area of the State, nearly 1,000,000 square miles, the coast-line is very small, being estimated at only 5,200 miles; for although the small portion north of the parallel 18° S. latitude is deeply indented, on the other hand, south of this parallel, the coast is marked by long straight reaches little broken by inlets, the only natural anchorages available, with the exception of Albany and Port Hedland, being roadsteads only partially protected.

The Harbours of Western Australia.

Responsible Government was granted to the Colony in 1889, and the great gold-discoveries of the next few years, with the resulting rapid increase of population, trade, and resources, enabled and compelled the newly enfranchised people to start extensive improvements of their estate, not the least of these being harbour facilities. These works have been prosecuted with considerable vigour, about £2,250,000 having been spent on them in the 10 years or so before 1904, in which year the Author's executive connection with the works ceased.

For the purposes of this Paper, however, attention need be directed to the marine works at Fremantle only, with some slight reference to those at Albany and Bunbury. These ports are the principal trade outlets for the area where the preponderating

APPENDIX F

settlement has taken place. The other works, distributed along the whole coast, consist of timber jetties, with their accessory tramways and other adjuncts, and have been constructed at places where the small population and trade did not warrant heavier expenditure. These jetties project, in the main, into the open roadsteads mentioned. For this reason, and also because of the great range of the tides and the violent cyclonic storms at many places, each work, though comparatively small, entailed considerable care, in order to make the most of limited means. Nevertheless, such works form a class by themselves; and although the destruction of one of the jetties in a violent cyclonic storm afforded valuable lessons, stress is laid, in the following physical descriptions, only on those features which affected the harbour-works in the south-western portion of the State.

The oldest rocks of the southern portion generally of the State are gneissic or granitoid, assumedly of archæan age, and geologists claim that this group of rocks is more largely developed there than in any other part of the world. They are greatly contorted, and, broadly speaking, now appear at the surface as four parallel belts striking roughly north and south. The third and fourth, or eastern belts, are far inland, except where they outcrop in the extreme south, and although connected so directly with the State's chief source of prosperity, the gold-mines, these belts do not require consideration here.

The second belt, which extends from the Murchison River to the south coast, forms the escarpment at the edge of the great plateau, the Darling range, the western edge of which is situated 20 to 30 miles from the coast. From this range and the inland plateau flow the rivers debouching near and at Albany, Bunbury, and Fremantle.

The first or westward belt also extends from the Murchison River to the south coast. The rocks composing it are comparatively soft, and, whether owing to denudation, attrition, or gradual submergence under the weight of superincumbent and later strata, the rocks of this belt south of the Irwin River are little exposed, except between Capes Naturaliste and Leeuwin, where they form a small range adjoining the coast. At Bunbury a basaltic outcrop and overflow forms an important headland, but the rock is apparently of a much later date than the archæan belt.

The stretch of country west of the second belt, that is, between it and the first belt or the sea-coast, consists of sandy plains, the result partly of the wearing away of the archæan rocks and of the later formations, which have evidently been greatly denuded, and

partly of seashells, including the remains of some of the minutest marine creatures. The deposits forming these sandy plains undoubtedly exhibit the characteristic false bedding of wind-blown material. Generally speaking, they have been more or less cemented below the surface into a sandstone or sandy limestone with irregular patches of purer limestone; but extensive sand-dunes, still exhibiting a tendency to travel, also occur along the western and southern coasts, at the river-mouths, or where the land is low.

Rain falling on this coastal area sinks at once into the ground, and the discharge, even of those rivers which have cut their way from the interior through the Darling ranges, is comparatively small. The many streams, therefore, that issue from these ranges do not now bring down much material, and, indeed, the volume of their waters is so small that the rivers are unable to do more than occasionally clear their mouths of extraneous sand.

In the north of the State the tidal range is large, but south of latitude 22° S. the maximum variation of water-level, and this dependent largely on the winds, rarely exceeds 5 feet, and is often a good deal less.

In the months of January and February strong currents set towards the land in the vicinity of Cape Leeuwin. The general current divides there, one part setting northward and the other part eastward along the south coast at the rate of 1 to $1\frac{1}{2}$ knot per hour. Several days before, and for some time after, the arrival of the north-westerly gales, a strong set to the south is usually experienced on the west coast. Near Fremantle the current generally sets between Rottnest Island and the straggling rocks in a N.N.E. direction during the summer or with a prevalence of strong S.W. winds, and in the reverse direction during the winter or with a prevalence of strong N.W. winds, at the rate of $\frac{1}{2}$ to $1\frac{1}{2}$ knot per hour.

Owing to the great stretch of ocean to the west, very severe storms are possible, and the south-west corner of Australia, Cape Leeuwin, has a bad name for them; but the resulting waves have not as much effect on the shore generally as would be the case if the sandy beaches did not exist. The winds on the west coast between North-West Cape and Cape Leeuwin are generally from some southern point, mostly between S.S.W. and S.S.E. During the summer they blow almost constantly from this quarter, but their regularity is interrupted in winter by occasional winds between north and west, which at times blow with considerable violence.

The sandy country, the small flow of the rivers, and the small

range of the tides, combined with strong winds and currents, have not only deprived south-western Australia of natural harbours, but have also closed all the rivers to navigation. Thus, taking the rivers from north to south, the mouths of the Greenough and Irwin are generally closed, the Arrowsmith does not reach the sea, and the Moore is too shallow for boats of more than 6 feet draught. The Swan was blocked by a bar, and the Murray has a bar with seldom more than 6 feet of water over it. The Leschenault inlet has a shallow sand bar across the entrance with seldom water enough for a boat; the common mouth of Wonnerup inlet and Vasse estuary is often closed entirely; and the Blackwood river has a bar with 4 or 5 feet of water in summer, and 6 or 7 feet in winter and after heavy freshets.

As in the somewhat analogous case of the west coast of the United States of America, the natural forces—winds and waves, tides and currents—although acting in the same directions all along the coast, have not produced the same results at all the rivers, owing, no doubt, to differences in the trend of the coast and to the interposition of such natural features as headlands. Thus the Leschenault and Swan, being protected from the south-west, have turned their mouths, or had them forced, permanently southward; while the Murray bar, on the other hand, when cut through by freshets, forms again from the south, the mouth of the river being forced farther and farther north, until finally closed.

Moreover, there are manifest signs in places that sand-drift, travel, and accumulation are still in progress. Thus, at Hamelin Bay the sand-drift has been gradually moving eastward, maintaining apparently a height of 150 feet on its eastern side; for, a few years back, the decayed tops of karri trees, just showing through the sand, were about the same height as those not yet enclosed: and at Busselton the coast-line has been moving steadily outwards, a long length of the old timber jetty having been buried in sand to the decking. Nevertheless, the extent to which the various bays and rivers are affected by continuous sand-movement, or even whether some are not so affected, has not been easily judged in the absence of continued observations; and, as will appear farther on, it has been exceedingly difficult for responsible engineers to advise with confidence.

The Albany and Bunbury Harbours.

The Albany or Princess Royal harbour is situated in the north-west of King George Sound on the southern coast, and is almost entirely landlocked. The circumvallation consists of granite peaks

connected by ridges of sandy strata, and the entrance is narrow. Although sand-drift and travel have, in the course of time, filled the large enclosed basin, there is not now much apparent movement of the sand, nor does any river flow into the harbour.

The works necessary and carried out from time to time to accommodate the trade of the port have therefore been comparatively simple, and have chiefly comprised dredging to widen and deepen the entrance-channel, to provide a suitable anchorage-basin, and to afford access to the timber jetties; these, with their accessory goods-sheds and railway-lines, a couple of lighthouses, and some beacons, complete the works executed.

The anchorage-area is now 350 acres, with 30 feet of depth at low water, and the channel to the town jetty is 400 feet wide and 23 feet deep. There is a swinging-basin abreast of this jetty. Up to September, 1903, about 3,225,000 cubic yards of material, consisting of sand, silt, shell, and decomposed or half-formed rock had been removed and deposited at sea.

The Bunbury harbour-works consist of three main items: a lighthouse on a commanding hill, a jetty jutting out into Koombana Bay, and a protecting breakwater.

The westernmost of the archæan belts previously mentioned is still in evidence from Cape Leeuwin to Cape Naturaliste, north of which lies Geographe Bay which, as already stated, shows marked evidence of coast-advancement. To the north of this bay the continuity of the coast-line is broken by the small indentation of Koombana Bay. This has resulted from a basaltic outcrop and overflow, which, while affording protection from the south-west, left the combined mouths of the Collie and Preston rivers exposed to the lesser but still important weather from the north-west. Although these streams with their tributaries drain an area of, roughly, 2,000 square miles, having an average rainfall of 31 inches per annum, their discharge, for reasons already stated, is too small to counterbalance the effect of the sand-accumulation caused by winds and waves. The mouth of these rivers, therefore, has been gradually forced southward and now lies under the very lee of the basaltic headland, the estuary being exceedingly shallow.

The small town of Bunbury is the natural port for a large district, but, the river not being navigable, it was not possible, in the earlier days of small things, to provide more in the way of harbour facilities than a naked jetty projecting into the bay. In 1893 the head of this structure, although in only 14 feet of water, stood 2,178 feet from the shore, exposed to every weather north of due west. So soon, therefore, as the increasing volume of trade brought

about the use of coasting and other vessels of deeper draught, the question of a better-protected harbour was forcibly brought to the front, especially when actual shipwreck occurred.

The physical features of the port clearly lent themselves to the formulation of two differing harbour-schemes, and two such schemes were submitted accordingly, in September, 1896. One was for an inner harbour, and the second, which was finally adopted, was for a curved submerged breakwater, to have an ultimate length of 6,000 feet, in extension of the basaltic headland, thus forming an outer harbour. The breakwater, which was ultimately built as a visible and not as a submerged structure, consists of tipped rubble stone. Shoaling occurred in the basin and at the outer end of the breakwater, but it is hoped that a further extension will cause the latter shoal to be scoured away by natural means.

Fremantle Harbour: Locality and Preliminary Schemes.

Attention has been drawn above to the evidence of sand-drift, travel, and aggregation at Hamelin Bay, at Busselton, and at Bunbury. North of the last-named there is for about 50 miles a succession of long shallow lakes or lagoons, separated from the sea by the sand-hills or dunes before referred to. The northernmost alone of these lakes discharges into the sea, the opening being maintained by the River Murray, which in heavy freshets cuts through the sand bar at Mandurah. The bar, however, regularly forms again, the mouth of the channel being forced more and more to the north until closed.

A few miles north of Mandurah there commence two parallel lines of reefs and islands, which bear N.N.W. and terminate in Rottnest Island. The deep gulf enclosed between the chains of reefs and islands and the mainland is termed Cockburn Sound, the northern portion being Gage Roads, into which falls the Swan River through an estuary (Fig. 1, Plate 7) which is tidal for about 20 miles. Although there is marked evidence, in the spits to the east of the various islands, of previous sand-travel, there is nothing now evident to show that there is present continuous growth of spits or shore—at least in positions to which resulting inconvenience would direct attention. Nevertheless, the possibility of silting of a harbour or its entrance, whether through continuous sand-travel or through local movement to and fro, has been a source of anxiety to every engineer who has had to deal with the design of proposed harbour-works in this locality.

There is ample depth over a large area and close to the shore in the sheltered waters at the head of Cockburn Sound. There are also, between the islands, channels of approach, which are capable of improvement and even now are used by vessels of moderate draught loading timber at the Rockingham jetty. But the seaport of Fremantle, small in the days before the expansion of the colony due to the gold-discoveries, was located at the mouth of the Swan River, Perth, the capital of the State, lying 12 miles up the river; and it naturally resulted that any new harbour-work must be built in the immediate vicinity of the mouth.

All that had been achieved by 1875 was the construction of three small jetties, one in the river in 5 feet of water, and two just south of Arthur Head, in 8 and 12 feet of water respectively. The bar at the mouth of the river prevented it from being used for navigation, while any jetty advanced beyond the shelter of Arthur Head became subject to the full force of the north-westerly weather. One of the two jetties shown was so advanced and improved from time to time, but the facilities obtained were not to be compared with those of the inner harbour since constructed, and the jetty is no longer in use.

The importance of obtaining a sheltered harbour was recognized, however, even in those early days, and notwithstanding the paucity of population and revenue—indicated in the following Table—the question was entered into with vigour.

Progress of Western Australia.

Year.	Population of whole Colony.	Revenue of whole Colony.	Railways in Colony.
	No.	£	Miles.
1829	Beginning of colonization.		
1875	26,709	157,775	Nil.
1877	27,838	165,413	Nil.
1887	42,488	377,904	168
1891	53,279	497,670	203
1902	215,157	3,690,585	1,360

Fortunately for the coming port, no minor work was put in hand, and in 1877 the matter was placed before the late Sir John Coode, K.C.M.G., Past-President of The Institution, who has left it on record that the various schemes of improvement proposed up to that date might be "briefly summarized as follows:—1st, works contemplating the provision of the required accommodation elsewhere than

at Fremantle; 2nd, works for the improvement of the river lying between its debouchure and the bridge which carries the road to Perth; 3rd, external works running from the shore into deep water; 4th, open-piled jetties; 5th, solid sheltering breakwaters detached from the mainland." It is interesting to note that the germs of his own proposals, made later, are contained under the fifth heading, and those of Mr. O'Connor, made later still, under the second.

Sir John Coode made two reports; one in November, 1877, based on papers submitted to him, and the other in March, 1887, after a few weeks' stay in the Colony. His reports show that the Colonial authorities were pressing for accommodation much beyond the needs of the time, and on the other hand, as an engineer responsible to the Crown authorities, he could not have been otherwise than struck and hampered by the fact that, compared with other colonies, Western Australia had made such small progress that, 60 years after the foundation of the Colony, the population was but little over 40,000, while the revenue was so small that the interest on any considerable capital expenditure would be a serious matter.

Sir John Coode, too, had evidently been given to understand that there was decided evidence of sand-travel. Those were days before the introduction of the suction sand-dredger, and, as already mentioned, the alleged certainty, or even the risk, of large recurring expenditure could not be incurred. His proposals, it will be seen, allowed for movement of sand along the foreshore, and so far they agree with those he submitted for Timaru, in New Zealand, where the shingle-travel was the largest he had met with up to that date. There the accumulation was subsequently found to be 80,000 to 100,000 cubic yards per annum, and later on he recommended that it should be dealt with by means of dredgers.

It would have been very interesting to see how his proposals for Fremantle would have been modified after the advent of an efficient suction-dredger, after the grant of responsible Government, and after the sudden increase of population and resources which a few years brought about. Even as they stand, the proposals demand reference in detail.

Another local belief was that storms in the locality were very violent, and—what is difficult to understand, considering the coast and depths in the offing—dread in effects. The Author reads Sir John Coode's proposals as showing that he did not consider wind and wave would be severe in effect, except where the works were broadside on to the direction of the worst weather. It is also clear that Mr. O'Connor, who reported later, was of a similar opinion. Nevertheless, the belief as to the severity of the storms in this locality

persisted for many years, and forced the Government later on to incur needless expenditure in order to induce the English mail-steamers to call at Fremantle when the new harbour was in a suitable condition to receive them.

In 1877 Sir John Coode's estimate for advisable works was £242,000, and writing later of these works, he said:—

"I arrived at the conclusion that the form of work at that time best suited to fulfil the conditions of the case would consist of an open timber viaduct 1,800 feet in length, extending from Arthur Head in the direction of the Beagle Rocks, terminating with a ˥ shaped solid pier, the two arms of which would be of the aggregate length of 1,500 feet. In addition to the foregoing, I proposed a spur jetty of 300 feet in length, to be formed at the junction of the viaduct with the solid pier, so that the total amount of berthage under this project would have been 1,800 feet in a depth of 20 to 27 feet at low water."

Reporting in 1887, after a flying visit to the State on his way home from Eastern Australia, and at a period of the year when personal observation was impossible, Sir John Coode said:—

"I had previously considered that these shoals [the Success and Parmelia banks, Fig 1, Plate 7], which are of remarkable shape, were merely accumulations of sand, and that their existence afforded strong if not conclusive evidence of sand travel to the southward and of the shoaling which would consequently result from the construction of any *solid* works extending *directly* from the shore. . . . I subsequently framed a further memorandum . . . requesting that borings might be made through the Success and Parmelia banks, in order that their character might be clearly and unmistakably ascertained. . . . From these additional particulars it is now clear that the banks referred to are accumulations of sand, and although the records of depth taken from time to time by the Admiralty authorities are not sufficiently numerous to enable their growth to be clearly traced and defined, nevertheless sufficient data are at hand to show that in all probability they are fed by the preponderating southerly movement of sand through Gage Roads and along the coast.

"Looking at the results of the supplementary borings on the Success and Parmelia banks, it would not be prudent to construct any solid structure in direct connection with the shore. To provide for the unimpeded movement of the sand, it will be requisite that any sheltering work at Fremantle should be detached from the mainland, the connection with the shore being effected by means of an open viaduct so arranged as to admit of the unrestricted passage of the sand without causing its deposition."

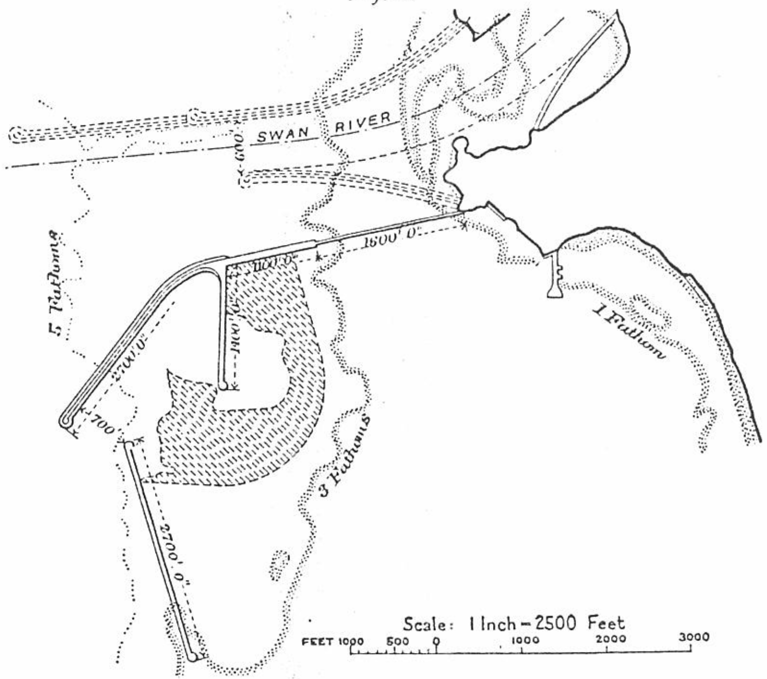
Works in Cockburn Sound being precluded, partly because of the vested interests of Perth and Fremantle, and partly owing to the alleged sand-travel, and an inner harbour in the river with an outer harbour formed by solid works connected with the shore being undesirable also on account of the alleged sand-travel, there remained only the alternative of an outer harbour connected with the shore by an open viaduct. The works of such an outer harbour would of necessity be broadside on to the worst weather.

In this connection, therefore, Sir John Coode wrote:—

"Gage Roads are open to the full stroke of the seas from N. to N.W. . . . The heaviest gales commence from N. to N.W. and travel westerly to about S.W., by which time they usually abate. These gales bring in heavy seas. . . . Whilst at Fremantle I had an opportunity of witnessing the effect upon the sea in Gage Roads of a very strong gale from the N.W. . . . This occurrence was so far fortunate as it enabled me to form a correct idea of the wave stroke that would fall on artificial works in a gale of unusual severity. . . . Having now had an opportunity of witnessing the force of the sea which would have to be encountered by these works, I am satisfied that nothing less substantial than structures of solid concrete would meet the conditions of the case in a permanent and satisfactory manner."

Sir John Coode's proposals, which, as previously stated, are of the greatest possible interest, were for works to be constructed in two successive portions. The first portion was for the accommodation of the trade of the time and a few years ahead, carried on in ordinary trading vessels, and the second portion was for the time when larger boats, such as the Peninsular and Oriental and the Orient mail-steamers, might be expected to visit Fremantle.

Fig. 2.



The first portion of the works, estimated to cost £495,000, was to have consisted of a root or abutment with sites for offices, warehouses, etc.; an open viaduct 1,600 feet long (*Fig.* 2), carrying two

lines of railway; and a right-angled concrete pier 37 feet wide, the arms of which would have extended 1,100 feet in continuation of the viaduct and 1,400 feet at right angles thereto, in a southerly direction. Berthage to the extent of 2,500 feet was to have been formed on the lee side of the two arms of the concrete pier, in depths, after dredging (included in the estimate), of 26 feet to 29 feet at low water.

The second portion of the works was to have consisted of two sheltering breakwaters, each 2,700 feet long, to be built of riprap with a capping of concrete suitably arranged. Their cost was put at £101 per lineal foot, or a total of £545,000.

The whole cost, therefore, of the accommodation for vessels of all classes was estimated at £1,040,000.

Nothing practical, however, ensued until, some years later, the late Mr. C. Y. O'Connor, M. Inst. C.E., was appointed Engineer-in-Chief. Applying himself particularly to the question of sand-travel, he came, after much personal observation, to the conclusion, and subsequently so stated, that the information supplied to the engineers who had reported previously was in his opinion erroneous; that he could not himself find evidence of sand-travel; but that, if it did exist, it could be counteracted by dredging in the manner that Sir John Coode had recommended in the case of Timaru, where, Sir John had estimated, the expenditure of £4,000 to £6,000 per annum would overcome the evil.

Such being his conclusions regarding sand-travel, and the Colony, by now granted responsible Government, having also progressed and being mistress of her own finances, Mr. O'Connor was able to submit a more comprehensive scheme, and decided that it would be best to open up the river. There was a choice between two methods of doing this; either through the bar at the mouth of the Swan, or by means of a channel through the narrow neck of land opposite Rocky Bay (Fig. 1, Plate 7).

The latter would have permitted comparatively easy access to Perth, and a comparatively easily-dredged basin of good size for ships to lie in would have been obtained. It is interesting, therefore, to note the reasons why Mr. O'Connor did not favour the Rocky Bay channel. In a report dated the 21st December, 1891, he said:—

"With regard to the Rocky Bay scheme, it has no doubt some advantages over an entrance at the mouth of the river, as it would be somewhat cheaper to construct, and has clearer exit into bold water. The navigation, however (unless an immense amount of dredging were done), from thence to Fremantle, would be somewhat tortuous, and the project has not therefore, I think, on the whole, sufficient advantages to warrant the creation of new interests, and the sacrifice of existing ones, to which it would no doubt have a tendency.

"If the railway had not to be crossed twice, and the main road also twice, the state of the case would be materially different; but the difficulty and expense which would be entailed by these four crossings (or by deviations of road and railway sufficient to obviate them), considerably counterbalance the other advantages of the Rocky Bay entrance.

The Scheme Decided On.

Choice therefore fell on the plan of opening the bar and constructing a harbour at the mouth of the river. The scheme, approved by Parliament early in 1892, was estimated to cost £800,000 for the bare harbour, exclusive of all accessories.

Fortunately, however, the continued progress of the Colony rendered it necessary that the scheme should be enlarged, and the cost to 1903, soon after which the Author left the State, was actually £1,458,940, made up in the manner indicated on p. 180.

The harbour constructed for this sum of money is in the mouth of the Swan River at the end of Gage Roads (Fig. 3, Plate 7). A main and far-showing light, high on Rottnest Island (Fig. 1, Plate 7) indicates the locality; a second and minor one at Bathurst Point, also on this island, enables it to be safely rounded; and a third, at Woodman's Point, directs vessels along the roads until the lights on the breakwater are opened. Between the moles a channel, 30 feet deep at low water, leads to a basin of the same depth, bordered on north and south by quays.

On the south the basin is well protected naturally by high ground, but on the north the narrow neck of land, more than once threatened and once breached by the sea, has been widened out, protected on its sea face by stone revetting, and provided with an artificial breakwind. On this side of the basin, the widening and reclamation have provided a considerable area of land, and the quay is laid with railway-lines connected directly with the railway system of the State.[1] On the south side reclamation has also provided a large expanse of land behind the quay, and partly on this ground are situated the sorting-sheds for cargo, and behind them the railway sorting-yards, in direct communication with the railway goods-shed and main station.

It was the Author's ambition that the harbour should receive an increasingly valuable endowment in the shape of a line of stores and bonded warehouses situated between the sorting-sheds and sorting-yards; but the idea does not appear to have been persevered in.

[1] The plan of the harbour (Fig. 3, Plate 7) refers to 1903, and the arrangement of the railway-lines on the south side was subject to alteration later.—C. S. R. P.

The North and South Moles.

The two moles or breakwaters which flank the entrance-channel (Fig. 3, Plate 7) are of unequal importance, as from the situation of the south mole the action of the sea on it can be relatively only small. The north mole, on the contrary, protects both the harbour-entrance and its fellow breakwater from the severest weather. In Fig. 5 are shown the cross sections of the two moles. The south mole remains practically of the length originally proposed in 1892, but the north mole was extended first of all by about 500 feet to 3,450 feet in length, and then by a further 1,350 feet.

With the exception of the parapet on the north mole, both breakwaters were built entirely of tipped stone, the stones being allowed to take their own slope; end-tip trucks were used to form the leading roads, and side-tip trucks for widening out. It was proposed in 1897 that the extension of the north mole by 1,350 feet should be a submerged breakwater, but it was eventually built to full height. Also, it was feared at first that this extension of the north mole might have to be of solid concrete, on account of the probable seas; but the success of the riprap system in the older portion determined the employment of this cheaper method in the extension also.

The cross section aimed at—that is to say, the slopes to which it was anticipated the sea might eventually draw the stone out—is shown in Fig. 5; and in order that there might be material enough for the flat slopes, a parapet, as shown, was tipped to the following approximate top widths of mole: south mole, 25 feet at the root, and 40 feet at the commencement of the round head, which was given a diameter of 80 feet; north mole, 30 feet at the root, 44 feet at 2,300 feet out, 52 feet at 3,300 feet, and correspondingly wider farther out. The rounded head at the inner termination was given a diameter of 130 feet, but that at the extreme end was made only 80 feet in diameter, which the Author determined would be sufficient, in view of the fact that better stone was then being used.

The stone used in the moles was of two kinds. From the levelling down of a portion of Arthur Head and from the quarry at Rocky Bay there was obtained a material which commenced by being an arenaceous limestone, or a calcareous sandstone, with a specific gravity of 2·64, which, according to Mr. O'Connor's calculations, would have produced a mole weighing 1·23 ton per cubic yard. But, as the Rocky Bay quarry developed, the quality of the

stone deteriorated; it was found to be both lighter and considerably more friable, and recourse was had to a new quarry at Boya, some distance inland. This yielded granite of good quality with a specific gravity of 2·73.

Work on the north mole was commenced in November, 1892, with stone from Rocky Bay, and it was completed as far as the 3,450-feet mark in November, 1895. The south mole was commenced in August, 1894, with stone from the levelling down of Arthur Head, but progressed very slowly until, on cessation of work on the north mole in November, 1895, the stone-trains from Rocky Bay were diverted to it, thus enabling completion to be effected in August, 1897. The extension of the north mole was commenced in July, 1899, and completed in December, 1902.

The south mole was constructed entirely of the limestone and sandstone described, and from completion in August, 1897, until the latter part of 1902, no repairs were required. In this year, in preparation for the permanent light-tower shortly to be erected, the extreme end—which had worn and subsided slightly—and the adjacent 150 feet were topped and faced on each side with granite.

The first portion (i.e. 3,450 feet) of the north mole, including the parapet, was constructed of stone of the same class as was used for the south mole, and so also was about three-fourths of the extension. But for the outermost portion it was considered better to use granite, and in 1902 the sandstone portion was given a coating of granite on the sea face.

During construction of this mole there was considerable loss and waste of the sandstone at the tip-head in stormy weather, the work advancing very slowly in the winter months. In one bad month in 1901 there was a loss equivalent to 2 per cent. of the whole contents of the mole between the 3,450-feet and the 4,500-feet marks. But, once the stone had settled into position, little occurred. Thus, for 2 years after completion of the parapet, on the original length of 3,450 feet of the north mole, only some slight flattening of the slopes took place. During the winter of 1898, notwithstanding several severe storms, only 6 per cent. of the reserve stone in the parapet was drawn into the sea slope. The expenditure on repairs was £700 in 1898–99, and thereafter no further outlay was incurred to December, 1900. It may indeed be said that only the anticipated clawing down of the slopes by the sea occurred, and the extent even of this was moderate, as is indicated by Figs. 6, Plate 7.

Dredging.

The entrance-channel of the harbour, shown in Fig. 3, Plate 7, is 450 feet wide for a length of 3,000 feet east of the 30-foot contour, and it then gradually widens out to 575 feet in the next 1,550 feet of length, where it may be said that the basin commences. From this point the widening continues until, at a further 1,800 feet, the full basin-width of 1,400 feet is attained. This width is maintained for 2,350 feet, and the basin was designed to narrow thereafter to the railway-bridge, which is 10,000 feet east of the 30-foot contour-line.

The cutting-down of the area shown as dredged, almost all to a depth of 30 feet below extreme low water, entailed the dredging of about 10 million cubic yards of material, exclusive of the quantity above water-level which was excavated in the dry and carted into the area to be reclaimed. Of the dredgings, about 2 million cubic yards consisted of rock, and the balance of sand and silt, much of which was too compact to be worked economically with a suction dredger.

By far the larger portion of the rock to be excavated was in the entrance-channel and the adjoining portion of the basin. Here, blocking the entrance, was the bar, consisting of a long rolling ridge of rock, principally coralline limestone and sandstone, which just across the mouth of the river showed a broad crest rising to low-water level (Fig. 4, Plate 7). Of the rock about three-fourths was drilled and blasted before being removed by bucket dredgers, and of the sand and silt about 30 per cent. was excavated by bucket dredgers and the balance by suction dredgers.

The engineering problem, therefore, was twofold: first, how to bring both bucket and suction dredgers quickly to work; and, secondly, how to dispose of the dredgings economically and to advantage. To these more strictly engineering conditions was added the imperative necessity of rendering portions of the harbour available from time to time for the rapidly advancing trade of the State.

The first requirement, therefore, was to cut a channel across the bar, and drilling- and blasting-operations were commenced in July, 1894. On the 30th of the previous month the north mole tip-head stood at 2,300 feet from the land end at Rous Head, so there was sufficient shelter from the direction of the worst weather. The drilling and blasting were conducted from stages, as explained later, and successive strips 100 feet or so in width were drilled and blasted to a depth of 15 feet below low water. This depth was completed in October, 1895, and the drilling and blasting of the northern half (225 feet) of the channel followed immediately. It was effected to

the full depth of 30 feet at first and the work progressed rapidly, but complaints being received that the heavy charges necessary were damaging buildings in Fremantle, the drilling and blasting had to be carried out in two lifts, the progress being slower and the cost enhanced. When this section was completed, attention was turned to the southern half of the channel.

Some of the ground had to be gone over twice where the rock bar was exceptionally hard, so as to save the dredgers. On the other hand, in the later stages of the work, when the northern half of the channel was in constant use by incoming and outgoing vessels, drilling and blasting were dispensed with, for fear of damage to the vessels, and the dredger was kept hard up against the rock to be removed, scraping away until the channel was entirely clear.

Dredging was practically started with a bucket dredger, the "Fremantle," which arrived from England in October, 1894, and commenced work at the seaward edge of the bar on the rock already blasted. By September, 1895, a channel 200 feet wide and 12 feet deep at low water had been cut through the bar, and the "Fremantle" passed into the river. She was followed, in January, 1896, by the suction dredger "Premier," which set to work on the sand in the inner basin. To these were subsequently added a second bucket dredger and a second suction dredger, all four vessels designed by Messrs. Coode, Son and Matthews, and built, the bucket dredgers in Scotland and the others in Holland. A tug and barges were also used, for a part of the time, to hasten the progress of the work.

In May, 1897, the S.S. "Sultan," an Australian coaster, made the first passage over the bar, the channel being 180 feet wide and 20 feet deep at low water. In October, 1897, the S.S. "Cornwall," an open-sea vessel, 420 feet long and of 5,480 tons burden, berthed in the river. By July, 1899, the German mail-boats successfully used the harbour, swinging in a basin then only 650 feet in width; and in July, 1900, the dredging was sufficiently advanced for the mail-steamers of the English lines to be induced to call regularly.

Of the dredgings, a small quantity of suitable stone was deposited on the line of the north mole, and about 3 per cent. was pumped by one of the suction dredgers on to the area to be reclaimed, still leaving nearly 9½ million cubic yards to be disposed of. It was decided that the most suitable dumping-ground for the dredgers and barges was along, and not far from, the shore north of the north mole. Contours of the ocean-bed adjoining the river-mouth taken in 1897 disclosed the proximity of the 2-fathom contour to the shore north of the river. This was dangerous; for a breach, in storms, of the narrow isthmus connecting Rous Head with the mainland (Fig. 1, Plate 7) had been threatened more than once, and had occurred once. Dumping of the dredgings was commenced, therefore, near the north mole and continued farther afield as each patch of ground was rendered too shallow for use. Ultimately the spoil was spread over an area bounded on the south by the north mole, on the west and north-west by the 3-fathom contour of 1902, on the south-east by the shore (as near, that is, as the dredgers and barges could get), and on the north-east by a line in continuation of River Street.

Of the whole quantity dredged and deposited in the years 1893–1901, namely 8,321,000 cubic yards, about 63½ per cent. remained within the area of deposition, and a further 17 per cent. was redeposited by the sea outside this area but within the limits of the soundings: of the balance, 113,000 cubic yards, or 1⅓ per cent., went to advance the foreshore, and the remaining 18 per cent. was entirely lost. An analysis of the weather-conditions in three periods from 1899 to 1901 shows that there was some correspondence between the weather and the percentage of dredgings drawn out to sea and lost to ken. These lost dredgings were not carried to the south of the harbour so far as the soundings showed, for comparison of the 1893 and 1903 contours disclosed the fact that south of the entrance-channel there had been practically no change in the ocean-bed. Even the patch south-west of the end of the south mole had remained in the same condition throughout the 10 years.

North of the north mole there have, of course, been changes, the foreshore and the 1-, 2-, 3-, 4- and 5-fathom contours all having advanced; but this, as already shown, can be ascribed to the sea having moved and distributed the dredgings. Between the surveys of 1902 and 1903 the 5-fathom contour due north of the north mole advanced markedly, and, on the other hand, the survey of 1903 also disclosed (Fig. 3, Plate 7) that the water opposite the narrow isthmus connecting Rous Head with the mainland was deepening and the foreshore was receding in this locality.

Within the harbour, however, and in the entrance-channel there had been very little silting, what there was, moreover, being counterbalanced by considerable scour in other parts of the inner basin. This area and a large portion of the entrance-channel were cleaned up between April and October, 1904, by a bucket dredger. The silt patches, also shown in Fig. 3, which formed by December, 1905, aggregated only 1,500 cubic yards, reckoning above the minimum harbour-depth of 30 feet below low water. As the sounding-line showed in the same month scour to depths of 40 feet below low water, it is probable that these silted patches are due to purely local causes.

Reclamation.

On each side of the basin was a considerable area of land which required to be cut down or filled up before it could be utilized for sheds and sidings, and early attention was given to this work of reclamation. The general levels fixed on were 10 feet above low water on the south of the harbour, and 13 feet on the north. The slopes of the earthwork were designed to extend below the timber wharves, and to have a protective facing of dry stone (Fig. 7, Plate 7) reaching down to the full depth of the basin. On the north, which was taken in hand at leisure, and where the filling consisted entirely of tipped material, the protective water face of stone was easily obtained; the stone was tipped on the top of the bank and gradually sank down, and was replaced at the top as a suction dredger excavated the basin to its full depth. The bank was coated to the bottom, and when the sloping protection had taken its set it was finished off at the top with dressed stone laid dry, in order to prevent nuisance from matter which might lie in the interstices of rough stone (Fig. 8, Plate 7).

On the south the reclamation had to be pressed forward, and the best method of construction was subordinated to a considerable extent to the exigencies of trade: also, the filling consisted partly of dredgings pumped on to the land, and partly of waste from the stone-quarry brought down in trucks. It was necessary, therefore, to provide a retaining-bank for the dredgings, with openings through which the water could drain out rapidly. The first work, consequently, was the construction of a bank from end to end, along the edge of the reclamation-area, 10 feet above water-level, and 20 feet wide. This bank had also to serve as the formation for an independent railway-line for the stone-trains from the Rocky Bay quarry to the south mole, and it was so used as soon as the railway-bridge across the Swan was completed and the north mole had reached its intermediate terminus.

The bank was faced on the harbour side with tipped stone. This would have slipped down as the dredging progressed, and a coating would easily have been obtained as on the north side of the harbour, but the work was rendered difficult, as the dredging could not be carried out fast enough for the circumstances of the case. Thus, orders were issued by the Government at the end of August, 1896, to commence wharf-construction, and by the 30th June, 1897, about 1,500 feet of quay was available for use by vessels, though the depth of water alongside was only 20 feet. By the 30th June in the following year the reclamation on the south side was completed,

and 4,450 feet of the south quay was available for use but the dredging was not complete adjoining any portion of the quay; the actual conditions were, 1,850 feet of wharf with 25 feet depth of water, 1,000 feet with 20 feet of water, and 1,600 feet with 12 to 15 feet. The result was that both the material below water and the excess stone above and below water remained badly disposed, as shown in Fig. 7, Plate 7. Matters were improved somewhat by the use of a small suction dredger to excavate under the wharf, but only part of the material could thus be moved, and it was not possible to employ a more powerful tool, for fear of damaging the ground below the sheds and a temporary passenger-station erected adjoining the quay.

The irregular disposition of the stone was not only a source of expense when the quay, constructed under pressure to accommodate traffic, was widened out to the present width, but was also a cause of serious nuisance, as the garbage which collected on the rough surface assisted in furnishing food for colonies of rats that lived in the interstices of the stonework; and these rats were a considerable source of danger in times of bubonic plague. In order to obviate these difficulties, the stonework, from the top to as low as the water would permit, was roughly "napped" to a face and coated with concrete, as shown in Fig. 9, Plate 7.

Wharfage.

The wharves or quays, which are of timber on timber-pile substructures, have an aggregate length of 9,255 feet, distributed thus (Fig. 3, Plate 7): north mole, 1,000 feet; south mole, 300 feet; jetty on the north side of the harbour, 900 feet on both sides; north quay, 2,000 feet; south or Victoria quay, 5,055 feet.

The wharves on the moles, which were built in 1897 to meet the great rush of traffic due to the rapid expansion of the State, are noteworthy because the piles of the substructure were driven into the moles, a fact which illustrates the softness of the stone and the hardness of the jarrah piles. These wharves have stood and answered their purpose well, notwithstanding the comparatively exposed position.

The jetty, which projects into the harbour from the north quay, was completed in 1900. It forms a part of the arrangements made to induce the vessels of the British-Australian mail-service to call at Fremantle, and it is a direct consequence of the mistaken ideas that prevailed in some quarters regarding the weather on this part of the Australian coast. It was feared that vessels moored against the south quay might not be able to get away safely to time in spells of bad weather. The Author believes the jetty has never

been used for the purpose it was built to serve, the mail-steamers having always found accommodation at the south quay, or having in time of bubonic plague remained at moorings in the centre of the harbour.

Of the two main wharves, that on the north of the harbour is one of the items which were designed while the Author was in immediate charge of the harbour-construction. The work in the wharf was straightforward; the piles, which are 12 feet apart from centre to centre each way, were steam-driven after the dredging was completed, and have successfully carried the loads placed on the wharf.

The history of the remaining wharf, the south or Victoria quay, in contrast to that of the other four, has been a troubled one, due partly, as previously stated, to efforts being made to provide harbour accommodation while the works were in an inchoate condition, and partly to divided counsels. Mr. O'Connor's proposals were framed to provide for easy transit inland of goods so destined, combined with as easy discharge of merchandise intended for Fremantle; while the Author hoped, by institution of free and bonded stores behind the quay, not only to assist in rendering Fremantle a great distributing-centre, but also to provide an endowment which would assist the managing authority to make of it a very cheap port indeed.

Mr. O'Connor desired the wharf and reclamation to be on the same level, with four lines of rails and hydraulic cranes on the former, to facilitate handling and distribution of cargo. As a compromise, two lines only were placed on the wharf, the cranes were dispensed with, and sorting-sheds were built on the quay, which was raised to 3 feet above reclamation-level in order to permit of easy delivery into carts conveying merchandise into Fremantle. New firms, however, not finding convenient situations in Fremantle, built their warehouses in Perth, the chief town of the State; and the older firms have had to follow the example set them. After the Author had left the State, he recommended the installation of electric cranes. These have been put in operation and have proved fully the advantage of equipping such a wharf with cranes; but the arrangements cannot be so satisfactory as if they had formed part of a complete original scheme.

In Fig. 9, Plate 7, is shown in plan the resulting quay, with its sorting- or transit-sheds existing and proposed. The westernmost 2,000 feet or so of the quay was built to 10 feet above low-water level and of the section shown in Fig. 7. It was subsequently widened. After the Author had left the State, the raising of this portion to 13 feet above low-water level was sanctioned, and a portion of it was raised. It was this 2,000 feet that was hurriedly built, as already mentioned, to accommodate traffic; it sank to some extent, and advantage was taken during the raising to strengthen the wharf by inserting extra piles.

Minor Works.

Of the minor works, three deserve some notice, namely, the slipway, the breakwind, and the lighthouses.

The slipway is situated at the root of the north mole (Fig. 3, Plate 7), and was intended to take vessels of a maximum dead weight of 650 tons and a maximum length of keel of 160 feet. It is a timber structure, the cradle being 185 feet long; and at ordinary spring-tides the depth of water over the keel-blocks, with the cradle at its lowest, is 10 feet 9 inches forward and 18 feet 6 inches aft. It was thus able to take any of the four dredgers used, which otherwise could not have received attention nearer than Melbourne, a good fortnight's journey, to and fro. The slip has also been of the greatest use to the smaller coasting craft.

The breakwind was erected to protect the basin from north-westerly gales, and it extends eastward from the root of the north mole for 2,200 feet along the low-lying isthmus north of the harbour (Fig. 3). It consists of quarry-refuse faced with roughly-dressed sandstone, laid dry, which is surmounted by an open picket fence consisting of 3-inch wooden uprights spaced 6 inches apart from centre to centre; the top is 45 feet above low-water level.

The five lights connected with the harbour were all obtained under the advice of Mr. W. T. Douglass, M. Inst. C.E. The main light, situated on Rottnest Island, is installed in a stone tower, and is 264 feet above sea-level at the focal plane. It is of the first order, dioptric, and with a single flash every 20 seconds. The second light, which enables Rottnest Island to be safely cleared, is situated at Bathurst Point. It is a fixed second-order dioptric light, 98 feet above low water at the focal plane. The third, or Woodman's Point light, directs vessels up Gage Roads until they open the harbour-entrance, where, at the end of each mole, there is a cast-iron tower 20 feet high, carrying a fourth-order fixed light.

There was some discussion as to the manner in which vessels should be directed up to the harbour, and at first it was proposed to erect two lights, one on Fish Rocks and the other at Woodman's Point. But it was considered that a cheaper and also better arrangement would be a single light at Woodman's Point throwing sectors of coloured light. That installed is fixed, of the first order,

and occulting, with its focal plane 126 feet above low-water level. The sectors, on the advice of Captain Russell, then Chief Harbour-Master of Western Australia, were so arranged that the westernmost or red sector can be used, if they so desire, by vessels of small draught, and the centre white portion by vessels of deeper draught, while the easternmost or green sector indicates dangerous ground.

Details of Cost.

Almost the whole of the work was carried out departmentally, and from the detailed accounts kept of expenditure and of work done the following particulars have been abstracted regarding the excavation of the channel and basin, which is divisible into two parts: first, the drilling and blasting of the rock, and secondly, the dredging.

It was essential that the drilling and blasting should be started quickly and pressed on with; to obtain special plant from Europe would have meant delay, and floating drilling-craft could not be satisfactorily employed, owing to the shallowness of the water over a large portion of the bar-crest and other parts; moreover, this rock was soft enough for the hand-drill, which was therefore employed and worked from stages. These consisted of light 30-foot planks carried on four-footed trestles with ladder-shaped tops, permitting of the planks being raised or lowered. In a couple of days 20,000 square feet of this staging could be placed in position, and it could carry 120 to 160 men, drilling with regularity in 20 feet and more of water. The holes were 8 feet to 12 feet apart, according to the quality of the rock, and the charge consisted of 12 to 15 lbs. of dynamite or gelignite, a ton of explosive sufficing for about 5,600 cubic yards of rock blasted. The expenditure on the various sub-heads of the work varied from time to time within limits, but approximately the total cost can be subdivided thus:—

	Per Cent.
Stages and other plant	16
Placing stages	6
Tugs, punts, pumping, etc.	4
Repairs to various plant	4
Stores, piping, drills and other tools	6
Explosives and blasting	16
Drilling	48
Total	100

The material dredged consisted in various parts of rock, blasted and unblasted, and of clay and sand; most of the sand was removed by the suction dredgers, but large quantites were excavated by the bucket dredgers, partly where it was too compact for removal by

the former, and partly when time pressed and it was necessary to clear particular areas quickly for commercial purposes. There were also large masses of weeds which clogged and hampered the dredgers and had to be specially dealt with. About 42 per cent. of the whole was removed by the bucket dredgers.

The whole cost of the dredging can be subdivided thus:—

	Per Cent.
Depreciation of plant	20½
Working of the dredgers	69½
Soundings, salaries of temporary staff, etc.	7½
Incidentals	2½
Total	100

The work of the bucket dredgers was too diversified for preparation of any complete subdivision of the whole cost of dredging by them; but the following Table shows the costs at Fremantle of the suction dredgers:—

—	Dredger "Governor."	Dredger "Premier."	
Period in which dredging effected	17/1/1900 to 30/3/1900	29/6/1898 to 27/6/1899	3/7/1900 to 2/7/1901
Volume removed in period . . . Cubic yards	221,785	720,377	801,059
Time dredger delayed in period :—			
For repairs . . . Hours	135	590	408
By bad weather . . ,,	5	332	410
By other causes . . ,,	53½	76	241
Total hours delayed	193½	998	1,069
Ratio of delays to whole working-time . . Per cent.	13	13	14
Volume dredged per hour of actual time worked . . Cubic yards	171	111	124
Items of Expenditure.	**Rate per Cubic Yard.**		
	Pence.	Pence.	Pence.
On salaries	0·19	0·34	0·24
,, wages of crew	1·23	1·59	1·41
,, coaling	0·08	0·10	0·08
,, watering	0·02	0·04	0·04
,, coals	0·71	0·60	0·64
,, stores	0·06	0·08	0·06
,, miscellaneous	0·16	0·18	0·23
,, repairs and renewals	0·59	1·03	0·94
,, workshops, supervision, etc.	0·14	0·28	0·19
Total	3·18	4·18	3·83

The total cost of the final scheme up to 1903 amounted to £1,458,940, distributed as follows:—

DETAILED COST OF HARBOUR-WORKS.

	£	£
North Mole:—		
To 3,450 feet—612,700 cubic yards	135,367	
From 3,450 feet to 4,800 feet—394,378 cubic yards	142,747	
South Mole:—		
To 2,040 feet—254,196 cubic yards	70,958	
		349,072
Wharves:—		
On North Mole, 1,000 feet long—51,285 square feet	14,419	
On South Mole, 300 feet long—14,604 square feet	4,992	
Victoria Quay, 5,077 feet long—296,136 square feet	122,686	
North Quay, 1,978 feet long—150,937 square feet	45,173	
Mail-boat jetty, 450 feet long—55,350 square feet	21,726	
		208,996
Reclamation:—		
North side of river—22 acres	22,865	
South side of river—54 acres	27,312	
		50,177
Dredging:—		
Drilling and blasting—1,503,099 cubic yards	238,345	
Dredging—9,637,501 cubic yards	455,298	
		693,643
Contingencies:—		
Breakwind—2,128 lineal feet	6,302	
Moorings	5,351	
Slipway, with cradle 185 feet long, for dredgers and other vessels up to 650 tons dead weight	21,644	
Office, etc.	4,566	
Land purchase	6,836	
Petty items	7,383	
		52,082
Total		£1,353,970

In addition expenditure has been incurred on—

Jetties in open harbour:—		
Main sea jetty	70,960	
Fremantle South	913	
Owens Anchorage, for explosives and stock	3,842	
Woodman's Point, for quarantine station	721	
		76,436
Lighthouses:—		
Rottnest, main	9,276	
,, eastern	3,114	
,, keepers' etc., quarters	1,619	
Woodman's Point	7,646	
South Mole	2,254	
North Mole, temporary	147	
Cable, mainland to Rottnest Island	4,478	
		28,534
Grand total		£1,458,940

COMMERCIAL RESULTS OF THE FREMANTLE HARBOUR-WORKS.

Recapitulating briefly the progress described in the foregoing pages, the works were commenced in November, 1892, when the first stone was tipped into the north mole; drilling and blasting of the ocean bar was started in July, 1894, reclamation on the south side of the river in August, 1895, and, under great pressure from the commercial community, the south quay was begun in August, 1896. In May, 1897, the works were sufficiently advanced for the first boat, the S.S. "Sultan," an Australian coaster, to make use of the harbour, the entrance-channel being then 180 feet wide and 20 feet deep at low tide. Finally, in August, 1900, the English mail-boat companies set their seal of approval on the works, the first vessel of these lines entering in that month. By the end of 1902 the works were so far advanced that an Act was passed constituting a Trust for management and maintenance, and this body took up its duties in January, 1903.

It is evident from this brief history of events during construction that the harbour was a great commercial necessity. This conclusion is emphasized by the facts that whereas in 1894 the whole tonnage of vessels visiting Fremantle was 337,820 tons (i.e., 406 vessels of an average net register of 832 tons), the corresponding figure in 1902 was 1,322,584 tons (657 vessels of an average of 2,013 tons), and in 1905 it was 1,462,995 tons (797 vessels of an average of 1,835 tons). This trade could not have been accommodated at all at the old outer jetty, on account of both its volume and the large size and deep draught of much of the shipping.

Financially, too, there has been a great saving, for the previous cost of handling, both from the jetty and through lighters, was excessive, whereas the charges in the new harbour are moderate, especially in view of the high wages paid in Western Australia. These charges consist, in the main, of three items: tonnage, berthage, and wharfage. The first, both inwards and outwards, is 3*d.* per ton on the registered tonnage of the ship or, alternatively, on the cargo, if this is less than one-fourth of the net registered tonnage. The berthage is 2*d.* per ton on the cargo, with a minimum of 5*s.* and a maximum of £20; and the wharfage is 2*s.* per ton on the cargo landed.

The net earnings of the harbour were £48,023 in 1903, £50,238 in 1904, and £52,511 in 1905, which on the inwards cargo only amounts to 1*s.* 4*d.* per ton. This may be contrasted with the profits of the old-established harbour of Melbourne, where the net earnings

in 1901 and 1902 averaged 1*s.* per ton, calculated on a fourfold volume, 2,822,000 tons, of combined inward and outward cargo. Looked at in another way, the financial results are also satisfactory, for the average interest on Western Australian Government loans was 3·41 per cent., and on this basis the annual interest on £1,353,970, the cost of the harbour-works, is £46,170 per annum, or, in round numbers, £2,000 less than the net revenue in 1903. The harbour is therefore one of economical design; moreover, at moderate expense it can be made to accommodate 50 per cent. more shipping than in 1904–5, and there does not seem any doubt that, on increase accordingly of the traffic and endowment of the harbour with storage-facilities, the port-charges could be so reduced as to lower the incidence of the net earnings from the present 1*s.* 4*d.* per ton to 8*d.* per ton, calculated on the inward cargo only.

It has already been pointed out that the late Mr. C. Y. O'Connor, C.M.G., M. Inst. C.E., prepared the scheme originally approved by Parliament. In addition, he controlled all alterations and took an interest in details to the time of his death in March, 1902. Of the Executive or Resident Engineers on these works at various times were Messrs. A. W. D. Bell, M. Inst. C.E., E. H. Carlin, William Leslie, J. A. MacDonald, M. Inst. C.E., G. H. Royce, and, in addition to his regular duties, the Author, who was also similarly concerned from time to time with all the other harbour-works, especially as Mr. O'Connor's successor in the position of Engineer-in-Chief of the State. Mention should also be made of Messrs. C. Good, T. C. Hodgson and J. Thompson, M. Inst. C.E., who dealt at various times as Executive Engineers with the many harbour-works of the State except Fremantle.

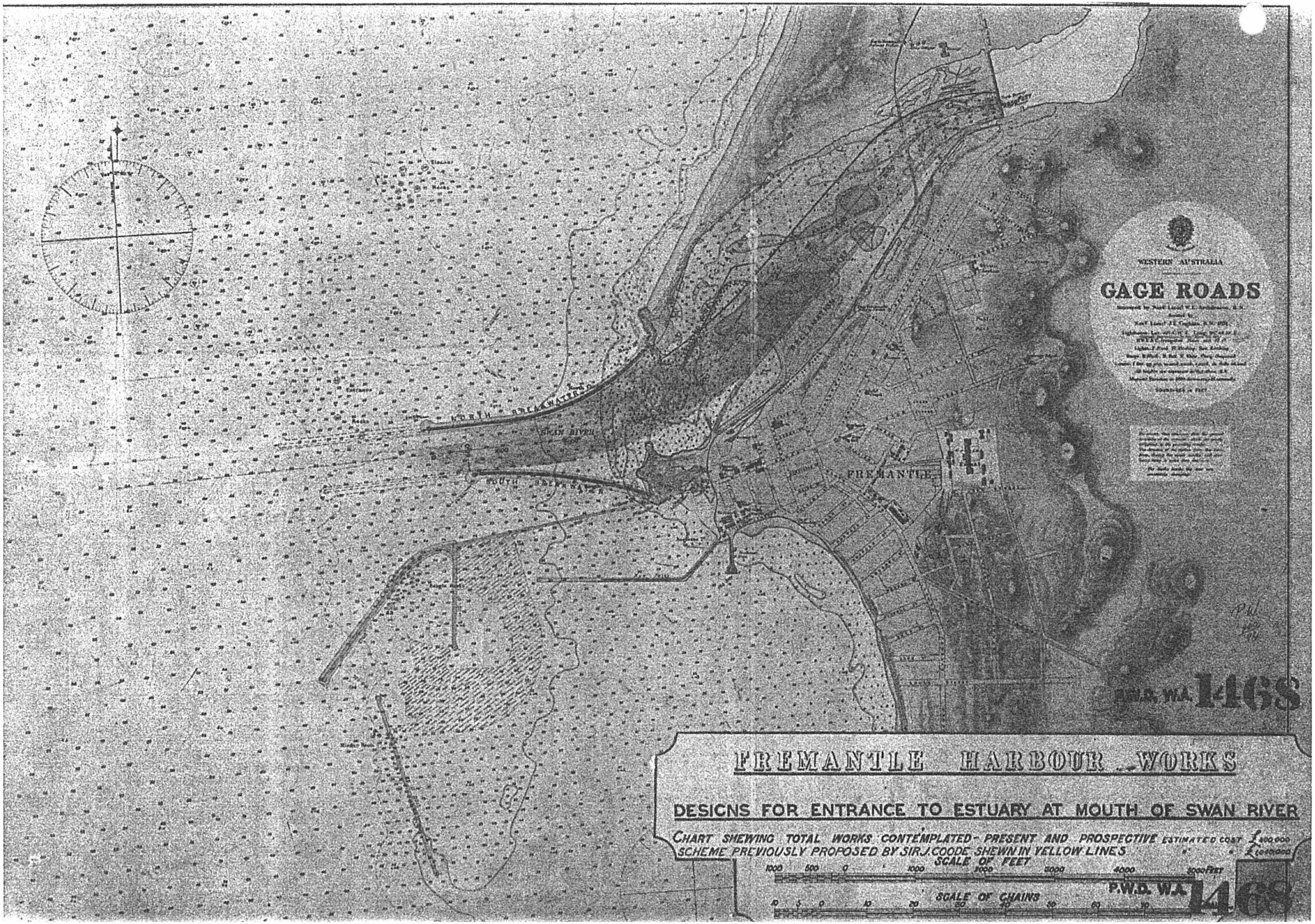
The Paper is accompanied by twenty-five sheets of drawings and maps, from which Plate 7 and the Figure in the text have been prepared.

Discussion.

The PRESIDENT, in moving a vote of thanks to the Authors, observed that the members would appreciate very much the fact that important harbour-works in Australia had been brought to the notice of The Institution in three very interesting communications—Papers which showed that the conditions in Australia were quite different from, he might almost say, anywhere else. The President.

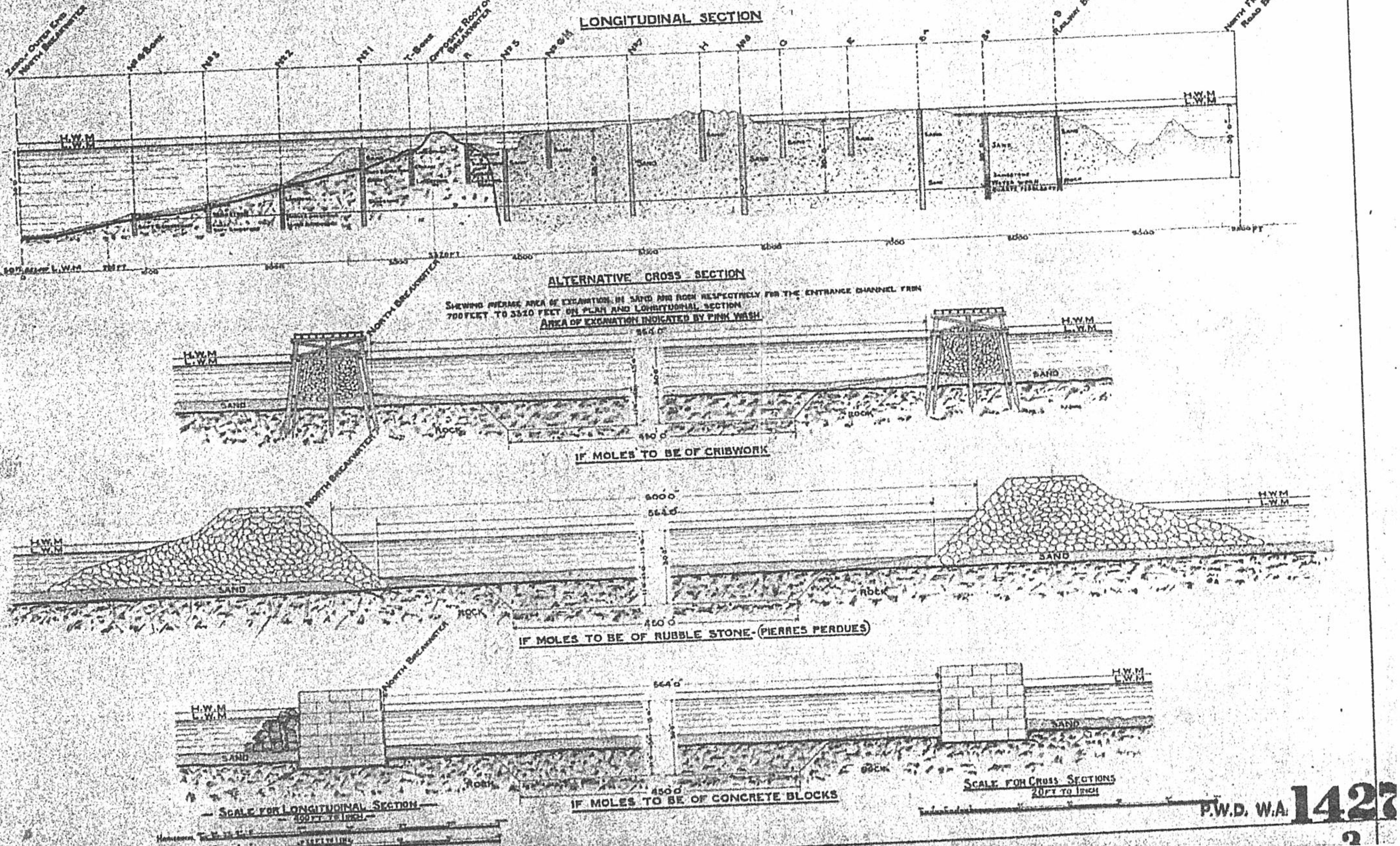
Mr. T. A. COGHLAN, Agent-General for New South Wales, remarked that he was very pleased to have the opportunity of hearing three Papers read on such an important question as the treatment of harbours in Australia. He was hardly in a position to say anything as to the merits of the Papers, and therefore he could not be expected to open a discussion upon them; but he felt that they were meritorious from the point of view of the researches made and the work done by the Authors; and the question whether the ideas propounded in the Papers were good or bad would be discussed by those competent to speak upon such matters. He was very glad to see that the Authors were not unmindful of their obligation to impart to their professional brethren in other parts of the world the results of their investigations and experience in Australia. In doing this they had availed themselves of the opportunities afforded by The Institution, whose work was known wherever civilization extended; and it was a very happy circumstance that engineers in the distant dominions of the Empire were welcomed to lay before The Institution their experience and ideas, and at the same time had the full satisfaction of knowing that they were placing them before a learned and impartial body. He desired to express his appreciation of the kind reception given by the members to the Papers, and he hoped the discussion would be fruitful of ideas and corrective of misapprehensions. Some of the theories put forward—especially those in Mr. Halligan's Paper—were in a sense novel, and he trusted that the discussion would be for the benefit not only of engineers, but also of the various States in whose employment the Authors were, or had been. Mr. Coghlan.

Mr. CECIL W. DARLEY observed that in discussing three Papers at once it was difficult to know where to begin—and perhaps still more difficult to know where to end. In Mr. Halligan's Paper some Mr. Darley.

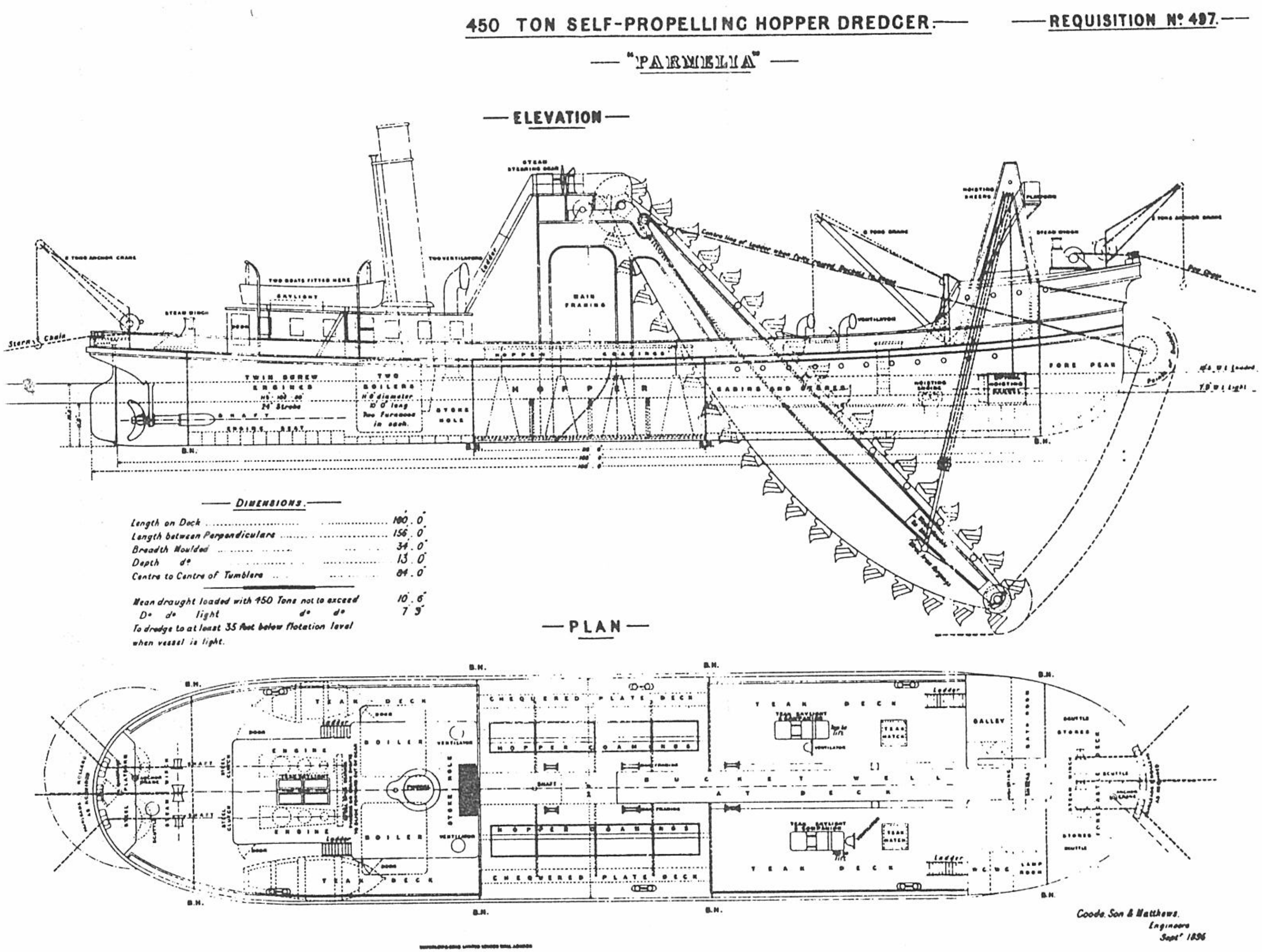

WESTERN AUSTRALIA
GAGE ROADS
SOUNDINGS IN FEET
NORTH BREAKWATER
SOUTH BREAKWATER
SWAN RIVER
FREMANTLE
P.W.D. W.A. 1468
FREMANTLE HARBOUR WORKS
DESICNS FOR ENTRANCE TO ESTUARY AT MOUTH OF SWAN RIVER
CHART SHEWING TOTAL WORKS CONTEMPLATED - PRESENT AND PROSPECTIVE ESTIMATED COST £800,000
SCHEME PREVIOUSLY PROPOSED BY SIR J. COODE SHEWN IN YELLOW LINES " " £1,020,000
SCALE OF FEET
1000 500 0 1000 2000 3000 4000 5000 FEET
SCALE OF CHAINS
10 5 0 10 20 30 40 50 60 70
P.W.D. W.A. 1468

FREMANTLE HARBOUR WORKS

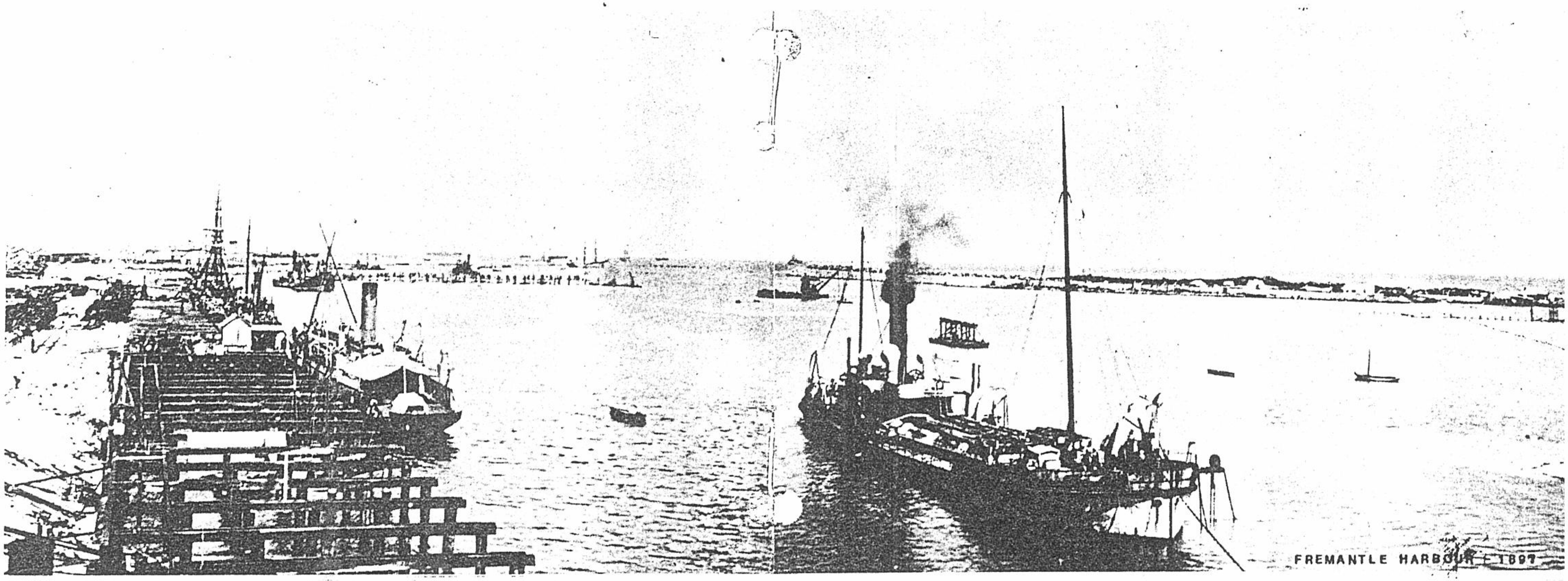
DESIGNS FOR ENTRANCE TO ESTUARY AT MOUTH OF SWAN RIVER



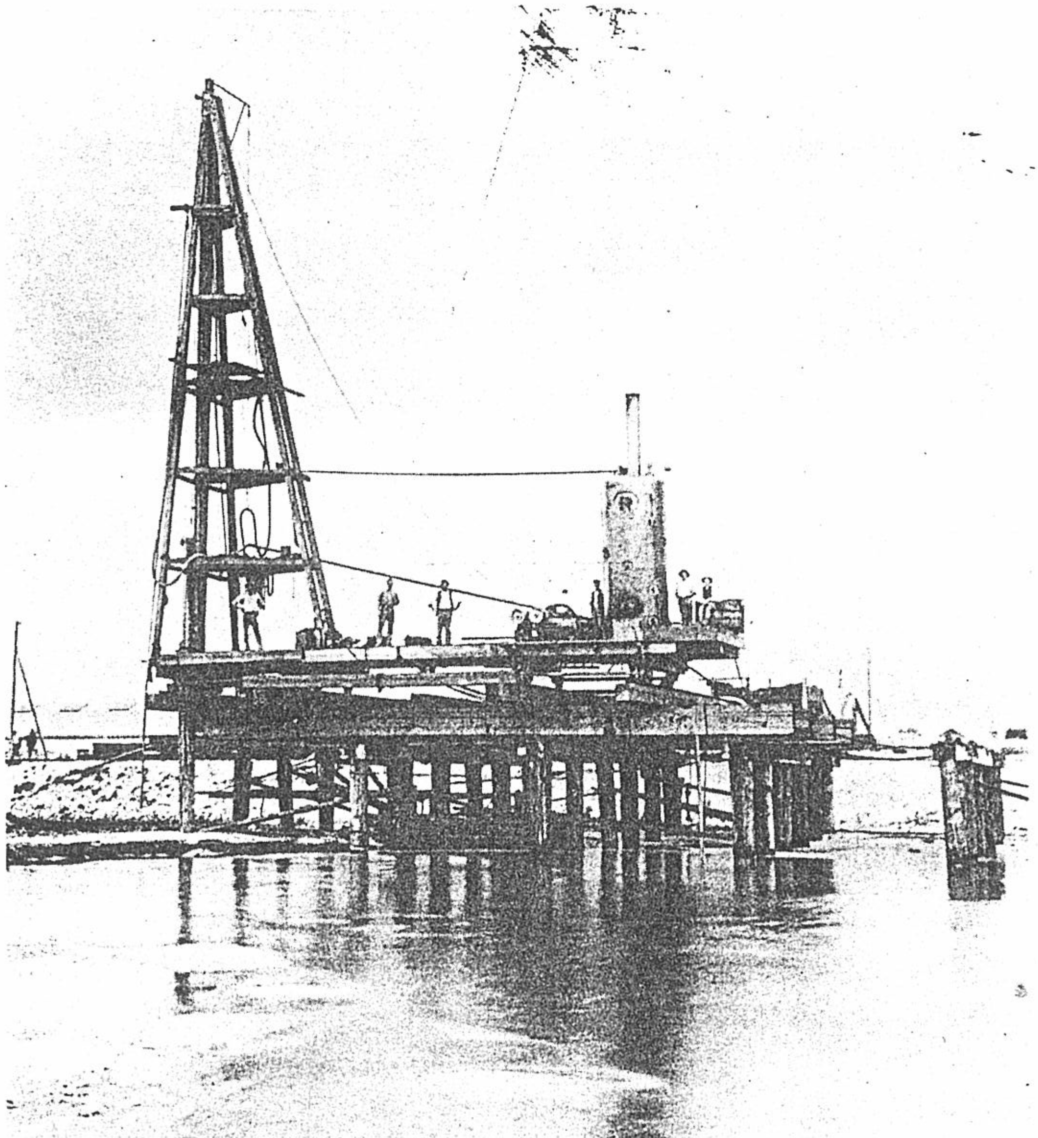
P.W.D. W.A. 1427



Bucket dredger *Parmelia*.



FREMANTLE HARBOUR c 1897



Fremantle Harbour, pile driver, 1897.